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An Economic Analysis of Space Solar Power and Its Cost Competitiveness as a Supplemental Source of Energy for Space and Ground markets

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ABSTRACT

Economic Growth has been historically associated with nations that first made use of each new energy source. There is no doubt that Solar Power Satellites is high as a potential energy system for the future. A conceptual cost model of the economics value of space solar power (SSP) as a source of complementary power for in-space and ground applications will be discussed. Several financial analysis will be offered based on present and new technological innovations that may compete with or be complementary to present energy market suppliers depending on various institutional arrangements for government and the private sector in a Global Economy.

Any of the systems based on fossil fuels such as coal, oil, natural gas, and synthetic fuels share the problem of being finite resources and are subject to ever-increasing cost as they grow ever more scarce with drastic increase in world population. Increasing world population and requirements from emerging underdeveloped countries will also increase overall demand. This paper would compare the future value of SSP with that of other terrestrial renewable energy in distinct geographic markets within the US, in developing countries, Europe, Asia, and Eastern Europe.

While the cost to develop space capabilities is high and in the order hundred of millions of dollars, the demand for low cost, and higher return is getting louder and more persistent. Therefore to live and plan for the realities of the 21st Century and continue the scientific exploration and commercial development of space markets it is necessary to develop a long term vision with ambitious exciting challenges and capabilities that would cost few billions of dollars over many years, but could be strategically achieved in complementary manner in reasonable small modular multi-million dollars components leading to a great integrated capability. This step-by-step approach is feasible within a small but stable long-term investment if the goals are properly selected, clearly defined and remain consistently supported overtime by the community leadership. Commercial exploration of space is a high cost, high value endeavor that will have a long-term social, technical impact on the future of the US, and the world. It will affect the balance of power and the social and operational fabrics of societies. It will change the balance of economical and technological power in the world with higher financial returns to the commercial stakeholders and the investors wherever they may be. Those countries/communities that identify clear goals first and initiate the incremental development will have a quantum technological and economical advantage that will be difficult to shake for at least a decade. Towards that goal one of the greatest factors that affect the future are energetics for power, propulsion for transportation, and high bandwidth communication for instant data management and processing. This paper looks at the implications of new approaches to electricity production from multiple sources solar, gas, coal, etc. in view of the possible economic regulation and environmental regulation for the environmental performance of the electric power sector. The first part of the paper will develop a review of the potential effects of a more competitive electricity market on emissions from the electricity sector and on the cost-effectiveness of environmental regulation of electricity suppliers. The review will include both developments in the United States and internationally.

1. INTRODUCTION

The American electric power industry is undergoing dramatic changes in the way it is structured and regulated. As of March 1, 1999, state utility regulators, state legislatures or both in 18 states had made the decision to implement retail competition within 5 years or less. Competition in electricity markets and associated new opportunities for expanded inter-regional electricity trading could result in substantial changes in the mix of generation technologies employed to produce electricity, in the efficiency of power plant operations, and in the price and quantity of electricity traded in the market place. The movement to competitive markets for electricity generation and retail sales is likely to thwart utility regulatory programs that support the development of renewables. Given the political support for renewable energy, state and federal legislators and energy regulators are considering a number of different proposals for encouraging the development and use of renewable energy resources as a component of plans to open the electricity industry up to competition.

The universal theme of deregulation of the electricity industry is the dismantling of the exclusive franchise. This march is now reaching full stride in the electric power industry, where most of the industry is privately owned and publicly regulated. At an increasing pace, electric power deregulation is spreading globally, though in a variety of forms, each designed to address specific preexisting market structure and political conditions. In countries and regions around the world, markets for electricity generation, and sometimes for retail sales, are opening up to competition. At the same time, electricity transmission and distribution remain regulated, although increasingly these functions are privatized. Hence, the deregulation of the electricity industry is more properly termed the "restructuring" or "liberalization" of electricity regulation and markets, because in virtually all cases the industry remains regulated in important ways.

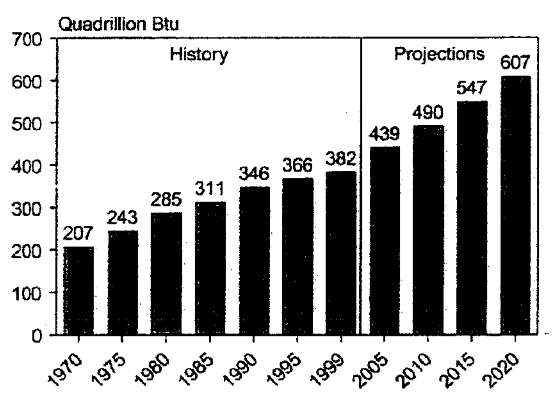
Electricity restructuring has several important implications for the environment. First, the electric power sector is a major consumer of natural resources and fossil fuels, and changes in the sector have a direct effect on resource use and prices. Second, electricity generation is a major contributor to air pollution, in some settings the major source of conventional air pollutants, including sulfur dioxide (SO2), nitrogen oxides (NOX) and secondary particulates derived from these gasses, and an important source of greenhouse gases and toxic air pollutants, including mercury. It is also an important source of pollutants to land and water, and of radioactive waste. Changes in the regulation of the industry affect incentives for the use of various facilities and fuels in electricity generation, and the resulting discharges to the environment. Third, changes in regulation are intended to have a direct effect on the price of electricity, which in turn affects the quantity of consumption of electricity and of its complements and substitutes. Fourth, changes in the economic regulation of the industry directly affect the incentive to comply with environmental regulation. All of these changes could in turn have potential implications for NOX emissions, with associated potential impacts on air quality in the United States as well as nitrate deposition at various part of the Globe. Researchers are focusing on how restructuring and concurrent potential environmental policies could affect emissions of NOX and CO2 from the electricity generation sector to characterize the changes that are likely to take place under alternative scenarios for regulatory and environmental policy. The electric power industry faces a host of new pollution control challenges. Major federal and state regulatory initiatives to reduce mercury, SO2, NOX, particulates, and greenhouse gas emissions from the electric power sector are simultaneously underway. At the same time, the industry is in the midst of a major restructuring that could have substantial implications for the effectiveness of both existing and new environmental regulations.

Researchers have noticed that an evaluation of policies to address any one of these environmental issues in isolation of the others is likely to misrepresent the opportunity cost of electricity production from various sources with respect to pollution control as well as the environmental benefits, and it is likely to misidentify the cost-effective policy to address a given issue. At the same time, an assessment of the effects of integrated control must be conducted in light of industry changes resulting from restructuring. For example, if restructuring leads to faster retirement of existing coal-fired and nuclear generators and increases the rate of investment in new gas combined cycle facilities, then that change in the rate and nature of capital turnover will affect the underlying rates of emissions of these various pollutants and the costs of new pollution policies. Similarly if a breakthrough in the technology occurs that enables more than 50% conversion efficiency of sun energy into electricity, the possibility of considering solar energy as a supplementary source of electricity increases drastically.

The U.S. electric power sector is facing a major and potentially costly change in regulatory limits on its emissions of nitrogen oxides (NOX). The current policy proposal of the Environmental Protection Agency (EPA) is motivated primarily by concerns about high concentrations of harmful ground-level ozone in eastern U.S. cities, of which NOX emissions are precursors. Electricity generators throughout the East are likely to be asked to reduce their summertime emissions of NOX by nearly 70% by the middle of the current decade. The proposal also includes a regional NOX emissions cap and a trading program in the eastern U.S. during the five-month "summer ozone season." However, the proposal largely ignores the potentially substantial benefits from reductions in atmospheric concentrations of particulate matter (PM) that would accompany reductions in NOX emissions, as well as reduced nitrogen deposition into certain ecosystems. Whereas benefits from reducing ozone occur almost exclusively in the summer, the other benefits would be realized throughout the year. When reduced particulate concentrations and other benefits of reductions in NOX emissions are taken into account, alternative policies may emerge as more cost-effective.

This paper analyzes the benefits and costs of policies to reduce the NOX emissions from electricity generation in the United States by the various sources of energy including solar and seeks to identify cost-effective approaches. The investigation makes use of the electricity market model, which estimates equilibria in the electricity market, including changes in the investment and retirement of specific technologies.

This analysis considers three NOX reduction scenarios that employ caps that vary by geographical and temporal coverage. All the caps are based on an average emission rate for NOX of about 0.15 pounds per million Btu (MMBtu) of heat input at fossil fuel–fired boilers. Our results show that the SIP Annual policy offers the greatest benefit-cost ratio based on particulate-related health effects, and it offers net benefits (benefits less costs) that exceed those from the other scenarios by at least a billion dollars per year. The particulate-related health benefits achieved by a reduction in NOX emissions are less than the costs of compliance in the scenarios. The design of a program to reduce NOX emissions will have an effect on the choice of technologies for reducing emissions and therefore on the cost and cost-effectiveness of the reductions. The design of the program will also affect the nature and magnitude of the benefits. NOX is a precursor to secondary pollutants, including ozone and particulate matter. Ozone has a widely recognized effect on human morbidity and potentially on mortality, though the latter effect is not firmly established. This technology standard translates into an emission rate standard of 1.6 pounds of NOX per MWh on an output basis The World Energy Consumption is shown in Figure 1.



Sources: **History:** Energy Information Administration (EIA), Office of Energy Markets and End Use, International Statistics Database and *International Energy Annual 1999*, DOE/EIA-0219(99) (Washington, DC, January 2001). **Projections:** EIA, World Energy Projection System (2001).

Figure 1. World Energy Consumption, 1970-2020

2. Changes in Technology, Consumption, and Price

To comply with the cap, emissions can be reduced in three ways. One is the installation of post-combustion controls. We model two types of post-combustion controls: selective catalytic reduction (SCR) and selective noncatalytic reduction (SNCR). A distinguishing feature of these technologies is that SCR is likely to have greater capital costs and somewhat lower variable costs than SNCR. Hence, the decision about which type of post-combustion control to install would be influenced by the expected utilization of a facility. Other things equal, a baseload unit that is utilized many hours of the year would be relatively more likely to install SCR, and a unit that is utilized fewer hours of the year would be relatively more likely to install SNCR.

3. Economic Costs and Benefits

The cost of post-combustion controls and any change in electricity prices are not the total economic cost of a policy. A complete measure of compliance cost would include the cost of switching fuels as well as the out-of-pocket abatement expenditures represented by post-combustion controls. And to electricity price increases, which affect consumers' pocketbooks, we must add the loss in well-being from a reduction in electricity consumption and the portion of the compliance costs borne by producers. To achieve a more complete measure of economic cost, one must estimate changes in consumer and producer surplus under various policies. Consumer surplus represents the difference between willingness to pay for electricity services and the price actually paid by consumers. Producer surplus represents the difference between revenues received by producers and the costs incurred in providing electricity service. In average cost regions, producer surplus is approximately zero, by construction. Another source of economic cost occurs in closely linked markets. In our model, all input prices are fixed except those for coal and gas supply, which have an endogenous fuel supply module that is price responsive and differentiated by region of the country and, in the case of coal, by fuel characteristics. Changes in demand for coal and gas lead to changes in price and producer surplus in the coal and gas supply markets. Although the changes in producer surplus simply reflect a transfer from the electricity sector to the fuel supply sector, they represent an economic loss in the electricity market.

Burtraw et al. (1998) examined the reductions in NOX and SO2 emissions resulting from the 1990 amendments to the Clear Air Act using the TAF model for atmospheric transport and health effects under similar assumptions. They find median benefits due to reduction in premature mortality stemming from reduction in nitrate concentrations to be $570 per ton of reduction in NOX emissions. The median benefits stemming from reduction in morbidity are $169 per ton of reduction in NOX emissions. The sum of effects is $739 per ton, accruing from reductions around the nation. Banzhaf et al. (1996) report on two studies of externalities from power plants in Wisconsin and Minnesota, but they look only at benefits within parts of those states and exclude benefits from long-range transport. They find benefits from mortality and morbidity improvements stemming from reductions in nitrates ranging from about $35 per ton of NOX reductions for a plant in a rural setting, to $366 for a plant in an urban setting. These numbers would be greater for a larger region or a more densely populated area. They also calculate potential damages for ozone and attribute all the damage to NOX as a precursor to ozone. They find ozone damages range from $29 (with an uncertainty range including zero) for a plant in a rural setting, to $358 for a plant in an urban setting. The estimates in Banzhaf et al. include both agricultural effects and human health effects. They find potential health benefits from emissions reductions of NOX and SO2 account for 56 to 80% of all damages. Agricultural effects are second, with damages of 15 to 25% of all damages. Materials and visibility effects are third, accounting for about 11% of all damages. The attribution of damages to category depends on the location of the plant. In a broad survey of three comprehensive studies done in the United States and Europe that examined externalities from electricity generation, Krupnick and Burtraw (1996) find that 82 to 93% of all quantifiable damages stem from the air-health environmental pathway when ozone effects are taken into account. The major component of quantifiable damage is attributable to the change in particulate concentrations. Together, these studies justify a focus on particulate-related benefits as a bellwether of the cost-effectiveness of a reduction program.

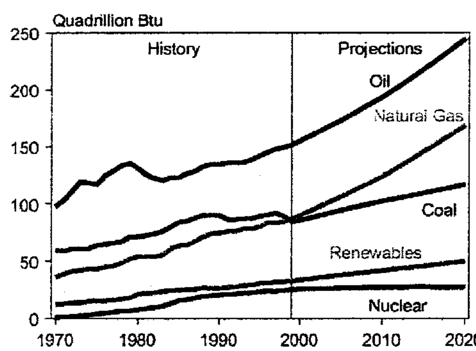
4. Electricity Regulation and the Introduction of Competition

Until the past decade or so, the electric power industry was widely viewed as a "natural monopoly," meaning the cost of generating, transmitting, and distributing electricity would be lower if only one firm undertook each activity. Generation is the process used to create electricity, usually at a central power plant. Transmission is the process of transporting electricity at high voltages, often long distances from where it is generated, to groups of electricity consumers. A majority of electricity customers in the EU and United States are now committed to reforms that will allow them the opportunity to choose electricity suppliers in the near future. Distribution is the process of transforming electricity to lower voltages and transporting it shorter distances to individual consumers. The existence of a natural monopoly in any of these components provides some justification for granting an exclusive franchise, for example, limiting operation in that component to a single firm.

Nonetheless, public policy tends to view exclusive franchise and other forms of monopoly with disdain for two general reasons. One concern relates to the inequity implicit in the ability of a monopoly to raise prices arbitrarily above production costs, enabling a transfer of wealth away from consumers and to the monopolist. To accomplish this feat the monopolist must reduce output below the level that would be supplied in a competitive market. This strategy raises a second concern that has to do with the loss of efficiency that accompanies the reduction in output. Hence, it has been widely acknowledged that if natural monopoly provides a cost-based justification for exclusive franchise, the broad set of desired social objectives—such as low prices and universal service—would not be achieved unless a market or regulatory institution exists to enforce these objectives. The resolution to the dilemma took a variety of forms around the world through the 20th century. One prominent model was public ownership, which is common at either the national, regional, or municipal levels in many countries. Such a model favors Space or Ground Solar Power which can be owned and operated by the consumer which was not possible with commercial gas or coal power generator because of the massive capital investment required. Another form was public regulation of privately owned firms. Typically, this arrangement involves oversight of investment and operation, and approval of tariffs. Granting of exclusive franchise affected both horizontal and vertical organization of the electric power industry. In the horizontal dimension, the exclusive franchise typically extended to each of the three primary components of electricity supply: generation, transmission, and distribution. Traditionally all three components of the electricity industry were considered natural monopolies. Today, however, electricity generation is no longer viewed as a natural monopoly. The introduction in the 1980s of new technologies, such as combined-cycle gas turbine plants, which achieve minimum average cost at a scale that is substantially smaller than a traditional steam-powered generating unit, further contributed to this change in views. Also, aerospace technology has contributed to the development of new gas turbines with capacities that are several times smaller still. These changes have undermined the perceived need to maintain monopoly in generation, with the promise that competition could better minimize the costs of production and promote incentives for innovation than can various forms of regulation or public ownership. Aerospace is once again leading the effort through breakthrough technological capability is power generation, power conversion, power management, and power storage to change the paradigm of the electricity markets towards private ownership thus reducing monopolistic tendencies.

The exclusive franchise has also affected the vertical structure of the industry. In most of the world, electricity suppliers have been integrated vertically and the exclusive franchise was extended beyond any single component to joint ownership and control of generating power stations, the transmission grid, and the distribution system. One argument for maintaining the status quo is the possibility that essential features of the quality of service, including voltage regulation and reliability of supply are better served through a vertically integrated monopoly. The notion is still widely held that transmission and probably distribution remain natural monopolies. But the perception of the need to operate the industry as a vertically integrated monopoly is fading. In its place are several alternative models that would enforce separation in the operation, if not in the ownership, of generating and transmission assets. The separation is intended to ensure equal and competitive access to the electricity grid for all electricity generators, while; it is hoped, to also maintain efficient and reliable integration with the transmission and distribution system. Finally, electricity has become an integral feature in debates about the environment. An important aspect of this debate is the appropriate role for renewable energy sources and technologies, which are usually viewed as more environmentally benign than conventional generation technologies.

In the United States, states that have restructured their electricity sectors generally allow for free entry into the generation market, subject to receiving the necessary environmental approvals. The extent of competition in generation markets depends on open access to the transmission and distribution systems. World Energy Consumption by fuel type is shown in Figure 2.



Sources: **History:** Energy Information Administration (EIA), Office of Energy Markets and End Use, International Statistics Database and *International Energy Annual 1999*, DOE/EIA-0219(99) (Washington, DC, January 2001). **Projections:** EIA, World Energy Projection System (2001).

Figure 2. World Energy Consumption by Fuel Type, 1970-2020

5. Transmission, Distribution, and Marketing

Almost all jurisdictions continue to view the transmission and distribution segments of the electricity market as natural monopolies. For this reason, competition has not been mandated for these segments. The exception is New Zealand, where these segments are privately owned and have been deregulated. Customers have recourse to pursue anticompetitive behavior through general mechanisms that apply in other industries. In other countries though, the transmission and distribution segments are most often tightly regulated with respect to prices and also are mandated to allow open, nondiscriminatory access to their networks. In some cases (for example, Ireland and Spain) generators who are denied access to the network are given the right to build lines connecting them with their customers.

Countries in the European Union are obligated to designate an independent entity to govern the dispatch of electricity over the high-voltage transmission network, and most other countries have also followed suit. The existence of a transmission system operator (TSO) also allows countries to enact feed-in laws, which make special exceptions to transmission access rules for either environmentally friendly technologies or technologies that are important to the economy (for example, domestic coal in the United Kingdom and East German lignite in Germany). In the United States, several regions of the country, including California, Texas, New England, New York, and the mid-Atlantic region, have created independent system operators (ISOs) with varying degrees of power. Some ISOs, including those in New England, New York, and the mid-Atlantic, also operate the centralized power exchange, while others such as those in California and Texas do not. All of these ISOs have independent boards and operate or coordinate the operation of transmission facilities that are owned by utilities. FERC Order 2000 also allows for the possibility of placing ownership and control of transmission assets with an independent privately owned and regulated transmission company; however, none are yet operational in the United States.

Table 1 shows a summary of the US and International Electricity Market Restructuring.

6. Determinants of the Environmental Effects of Restructuring

The effect of restructuring on the environment consists of four constituent influences. Three of these influences are economic. One is the influence of changes in output, or output substitution, including the change in the consumption of electricity in the economy and how

Table 1. Summary of International Electricity Market Restructuring*

	Generation	Transmission	Distribution	Marketing	Ownership	Timing	Special
UK	Fully competitive with seven major competitors	Regulated monopoly; price cap with productivity adjustment	Regional regulated monopolies	Fully competitive	Formerly publicly owned companies have been privatized	Gradual phase in now complete	Temporary moratorium on new gas plants to protect domestic coal concerns
EU	Member-state specific, most with authorization procedure for new capacity	Regulated monopoly with open access rules; either negotiated or regulated 3rd party access (TPA).	Most with regional distributors acting as regulated monopolies	Mostly competitive; some distributors acting as single regional buyer	Network assets do not need to be divested, but accounts must be unbundled	Gradual; by 2003, one-third of all customers with right of choice	Reciprocity rules so that early movers are not punished
Germany	Fully competitive	Negotiated TPA to grid; very little regulatory structure	Regional regulated monopolies	Very many small fully competitive companies	Accounts must be unbundled, and prices must be nondiscriminatory	Immediate; all customers already with choice	Protections for East German lignite until 2003
Norway	Fully competitive with plans for pan-Scandinavian market	Regulated monopoly with open access for all generators	Regulated monopolies	Fully competitive	Municipal and federal utilities have not been privatized	Gradual with fees for choice reduced and then eliminated	99% of Norwegian generation is from hydroelectric sources
Alberta, Canada	Competitive but dominated by three firms	Owned and operated by independent entity; all transactions must go through the power pool	Same as Transmission	Mostly competitive	Generation companies divested of control over transmission assets	Gradual, with full customer choice by 2001	Creative policy requires utilities to sell power through independent marketers who in turn sell power in the pool; decreases market power
Argentina	Fully competitive with 30 generation companies	Six private transmission companies, tightly regulated; price cap with productivity adjustment	Mostly municipal utilities	Competitive through the power pool using merit-order dispatch and bilateral contracts	Recently privatized companies given long-term concessions for the operation of government-owned entities	Rapid change as companies were privatized in early 1990s	Most of the newly privatized companies are controlled by foreign interests
Central America	Semicompetitive; country-specific	Regulated prices with guaranteed open access	Same as Transmission	Presently the market in each country acts as a single-buyer from the larger regional market	Country-specific; some still publicly held	Partial regional integration by 2001, full integration by 2004	Many of the details have yet to be worked out
New Zealand	Fully competitive with 75% of sales going through the central market	Unregulated	Unregulated; all distributors must maintain connections at least to the same extent as in 1993	Fully competitive	The 3 largest generation companies are still government owned; complete separation of ownership of vertically integrated companies by 2004	Immediate	60% of generation is from hydroelectric sources
California	Competitive with free entry; central market run by power exchange	Regulated monopoly; Price cap regulation; operated by ISO	Regulated monopoly	Competitive	Substantial divestiture of generation by T&D utilities	No phase in; electricity price capped and fixed until stranded costs recovered	Surcharge funded subsidy to support renewables
Pennsylvania	Competitive with free entry; central market run by the ISO	Regulated monopoly; grid operated by regional ISO	Regulated monopoly	Competitive; ~7% of electricity consumers have switched providers as of July 2000	Vertical integration allowed, but open access required	Competitive phased in over 2-yr period starting January 1, 1999. Stranded cost recovery extends for up to 9 years	
Texas	Competitive with free entry; no official centralized market	Regulated monopoly with an ISO that administers transmission access	Regulated monopoly	Competitive ; limits on price reductions that distributed utility can offer customers in its service territory	Separate affiliates for different functions	Competition phases in over 6 months, starting June 2001	Requires stricter environmental controls on older plants; requires 50% of new capacity to be fired by natural gas

*Burtraw, Palmer and Heintzelman, September 2000 (Report) it substitutes for (and complements) the consumption of other products. A second is the influence of input substitution, which refers to the substitution among fuels and other inputs in electricity production. The third is efficiency improvements that stem from the influence of competition on productive efficiency and endogenous technological change. Finally, a fourth influence is the interaction of firm behavior and market structure with existing and new incentive-based approaches to environmental regulation.

7. Output Substitution: Falling Prices and Growing Consumption

A primary motivation for allowing competition in electricity markets is the expectation that, in general, prices to electricity consumers will fall. The effect of price declines would be to encourage substitution toward increased electricity consumption. This change in itself raises concerns and the objection that restricting growth in demand should be the top environmental priority (Ferguson 1999). However, Brennan (1999) describes the possibility that the need for environmental policy could fall, not rise, with a reduction in the cost of electricity. This finding holds in a competitive market if demand or supply is sufficiently inelastic to keep market output from changing much. In this case, the welfare loss from inefficient overproduction of the dirty good will fall as its production costs fall. The same result holds in a regulated market, or under the process of restructuring, if production of the dirty good exceeds efficient levels and output does not change much as costs fall. However, if production was below the efficient quantity, perhaps due to the influence of market power, the addition of environmental controls could lower welfare. Furthermore, though the majority of the literature in the context of electricity restructuring has presumed potentially significant increases in output, from a broader perspective the substitution of electricity consumption for consumption of other fuels in end use—in other words "output substitution"—is likely to have environmental benefits

8. Input Substitution: Fuel choice and the Rate of Capital Turnover

For any given level of electricity demand and fixed set of environmental policies, the environmental effect of restructuring will depend on what happens to the mix of fuels and technologies used to generate electricity. One pessimistic scenario foretells that restructuring will reduce the penetration of zero-emitting (at least of conventional air pollutants) technologies such as solar power and renewables. Nuclear will still require very high capital investment and is associated with tremendous consequences in space of an accident like Chernobyl in the Ukraine, Another more optimistic scenario envisions new entry of merchant generators using highly efficient and low-emitting gas-combined cycle units and combustion turbines. This approach would be complemented by anticipated strong market demand for "green power"—power from nonfossil or relatively environmentally friendly technologies— such as space solar power, leading to a cleaner fleet of generators and lower emissions in a competitive world. Other mixed scenarios have also been suggested with more uncertain net impacts on air emissions.

a) Prospects for Nuclear Generation. Nuclear power is a significant source of generation for much of the world. Although the disposal of nuclear waste is associated with substantial environmental problems, nuclear power plants do not emit conventional air pollutants or carbon dioxide. Thus, from an air pollution perspective at least, nuclear power is clean. The prospects for nuclear power have faded with concerns about their financial performance. Nuclear power is also a very significant source of potentially stranded costs as countries begin to deregulate. As part of restructuring in the United Kingdom, the government planned to sell its nuclear assets in 1989 but found that the combination of decommissioning costs, spent-fuel reprocessing costs, and liability made nuclear assets hard to sell. The government then instituted the Fossil-Fuel Levy as a way to subsidize nuclear power until all the generators were sold as British Energy in 1996. The eight most advanced plants were sold for $2.2 billion, which accounted for the costs of all but one of the plants. The government absorbed the remaining cost. Likewise, the government also took on the cost of the older plants that could not be sold. Sweden is another country with significant nuclear assets. However, Sweden has committed itself to phasing out all nuclear power production by 2010. Whether this phase out will be achieved remains subject to question, but the first plant was closed in 2000. It is possible that due to this phase out of nuclear power, deregulation will have little or no effect on the nuclear issue. The government is stranding the costs of nuclear power by 2010 regardless of other policies, so any stranding that is done by competition would not affect the nuclear complex. The German government has also reached an agreement with its utilities to phase out nuclear generation by 2030. They plan to achieve this phase out through the use of an aggregate cap on total nuclear generation during the intervening years where the right to generate power will be tradable among generating facilities.

In the United States, absent a change in public policy and in public attitudes, no new nuclear power plants are likely to be constructed in the near future, so the percentage of generation from nuclear plants will diminish as electricity demand grows and as operating licenses of existing plants expire. Competition may result in early retirement of some portion of the existing nuclear capacity. In a regulated environment most nuclear power plants would be expected to remain on-line at least until the expiration of their current operating licenses. At market prices, a few nuclear plants will be unable to cover the costs of fuel, operation, and maintenance, and meeting safety requirements. Estimates of the annual amount of nuclear generation potentially subject to early retirement range from 40 billion kWh hours per year to over 110 billion kWh per year, or 6.3 to 17.5% of current levels of nuclear generation. The bottom line for nuclear generation in the United States is still highly uncertain. The official analysis of the Clinton administration's Comprehensive Electricity Competition Act of 1999 forecasts that increased generation resulting from future productivity improvements at existing nuclear plants will more than offset the generation lost due to premature nuclear retirements (U.S. Department of Energy 1999.

b) Prospects for Solar Power and Renewables. Renewable generating technologies, or simply renewables, include all forms of generation that use a nondepletable energy source. This category of generators includes hydropower, solar thermal and photovoltaics, biomass, geothermal, and wind power. Like nuclear power, most renewables do not contribute to emissions of conventional air pollutants or of carbon dioxide. Renewables represent a small fraction of total electricity generation in the world. However, policies can be effective at accelerating the introduction of new technologies. Efforts to promote renewable technologies in Europe have led to a 200% increase in the installed base of nonhydro renewable-generating capacity from 4.8 GW to over 15 GW. Typically, renewables are land-intensive, which can have environmental implications. Moreover, as the industry transitions to greater competition, some of the regulatory mandates and programs that have helped to support the use of renewables in the past are disappearing. All of these factors suggest that absent new environmental policies or a strong expression of preference for green power in a restructured marketplace, renewables will be less likely to penetrate the market.

The size of the potential market for green power is difficult to estimate. In the United Kingdom, a consultant report found that 10% of respondents to a survey of U.K. Businesses would be willing to pay a 7% premium for renewable power.25 Similar findings have been found in marketing surveys in the United States. Surveys of residential customers indicate a majority of 52–95% say they are willing to pay at least a modest amount more per month for electricity from renewable sources. Reality indicates a difference between stated preference and revealed preference, though, and a substantially smaller percentage of the customers eligible to do so have purchased green power to date. Though the California law allows customer choice, it provides no incentive for customers to consider switching away from their incumbent providers. Grown in Electric Capacity Supply 1995-2020 (GW) is shown in Figure 3.

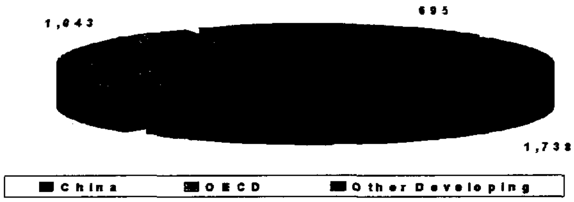


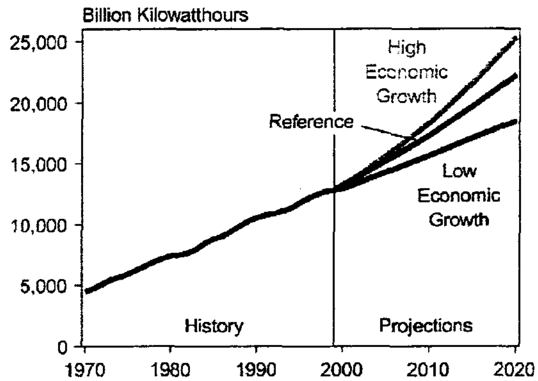
Figure 3. Growth in Electric Capacity Supply

9. Efficiency Improvements: Stronger Incentives for Efficiency and Technological Improvement

Greater competition is expected to hasten the improvement in performance of existing facilities and the introduction of new technologies. In fact, the portion of the time that existing facilities are available for generation when needed for generation, known as the "availability factor," has been increasing over time and many analysts associate improvements in the past decade with the prospect or reality of competition. Under competition, increasing availability creates an opportunity to earn greater revenues per unit of invested capital, thereby increasing profits. At the same time, major research institutions like the Electric Power Research Institute have suffered a loss of funding from individual member companies faced with stiffening competition and a need to cut costs. It is possible that firms could face even greater rewards from innovation in a competitive environment than under regulation. However, it remains to be seen whether private incentives are sufficient to encourage R&D, especially with respect to new technologies that may have a longer gestation before they are practical. Some observers fear that competition will slow the pace of technological improvement and lengthen the wait until new environmentally friendly technologies become practical. The World net Electricity Consumption is shown in Figure 4.

10. Technology Development Effort

The future evolution of SSP, like that of any technology, will depend on paths chosen for its development, and the physical and fiscal resources brought to bear to commercialize it. An early priority is demonstrating that power transmission between the Earth and orbiting satellites is feasible with near-term technology. The logical first step is to design a set of demonstration experiments to test the efficiency and cost-effectiveness of line-of-sight power beaming through the atmosphere over hundreds of kilometers by



Sources: **History:** Energy Information Administration (EIA), Office of Energy Markets and End Use, International Statistics Database and *International Energy Annual 1999*, DOE/EIA-0219(99) (Washington, DC, January 2001). **Projections:** EIA, World Energy Projection System (2001).

Figure 4. World Net Electricity Consumption in Three Cases, 1970-2020

employing "off-the-shelf" or readily modified radars and laser space systems. Theoretical considerations and initial studies suggest existing satellite antenna hundreds of kilometers away in space could receive >100 kW from peaking radar pulses from Earth. The focus is on exploiting innovative methods to "snap-on" and retrofit SSP demonstration capability to existing satellite systems, with an emphasis on bootstrapping and low-cost methodologies for orbit-to-Earth and Earth-to-orbit beaming demonstrations. Earth-based demonstrations will be pursued as well; and contact made with research teams around the world with a view toward cost-effective collaborations and participation by developing nations in SSP demonstrations. The next logical step in Wireless Power Transmission is measuring the fraction of transmitted energy in a diffracting microwave beam over the hundreds of kilometers separating orbiting satellites from the surface. As a consequence of Earth's curvature, and to avoid putting heavy power supplies or large area PV arrays in orbit, the most cost-effective test of focused microwave power beam transmission over hundreds of kilometers may be to transmit powerful microwave pulses from phased-arrays on Earth to satellite antennas. The identifying and tracking of the technology development effort is shown in Figure 5.

<u>a) Technology Needs.</u> Technology requirements for Space Solar Power in support of short term and long term NASA opportunities and needs are shown in Table 2. Space Solar Power technology will have matured to a level that will enable a demonstration in space that, if done in quantity of 50 satellites, can produce electricity at a cost of 30 to 60 cents per Kw-hr

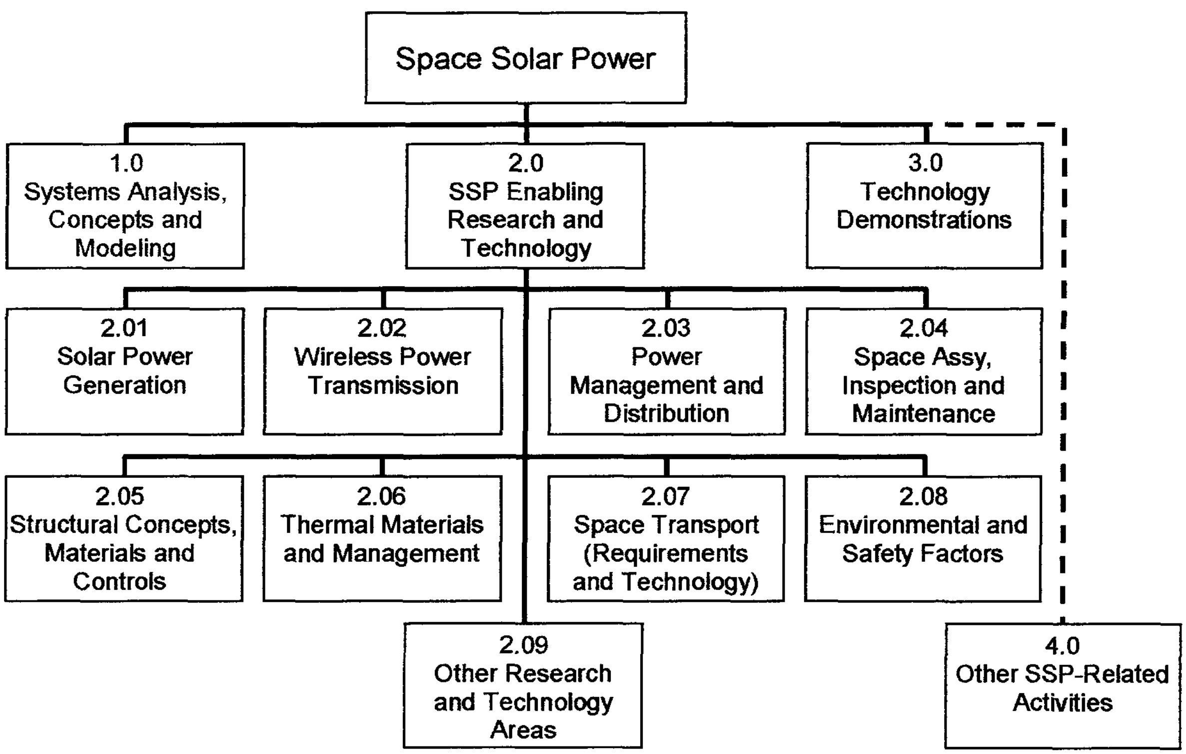


Figure 5. Space Solar Power Project Work Breakdown Structure

Table 2. Opportunities to Deliver/Support – Products of Importance to NASA

5 Years	10 Years
• 50m Ultra Lightweight Structures for Large Aperture Observatories, Solar Sail, Interferometers	• 10–50 kW SEPS for Space Science • 200 meters Light Sail
• 200 Watts/kg SPG for Earth Science, Space Science and Commercials	• 1 kW/kg SPG for Space Science and HEDS, tenfold reduction in SEPS
• Ground to Space Power Beaming for Space Science • Ultra Large Lightweight Optics	• Ground to Space and Space to Space Power Beaming for Interstellar, Space Exploration Resources Utilization and Asteroid Retargeting
• Dether System Application for Transportation, Power Generation and Rotating System • Cooperative Robots for Discovery and Science Missions	• MW SEPS for HEDS • Non-nuclear Deep Space Power
• Very High Temperature Devices/Materials for Space Science	• 100 – 1000 kW Power Utility in Space for Government and Industry
• Autonomous Deployment of Spacecraft and Servicing of Science Missions	• Intelligent Distributed Space Systems
• WPT for Commercial Application	• Advanced Spacecraft Servicing for Earth and Space Science Missions
• Highly Automated Ground and Space Systems Operations (Vehicle Management)	• Very High Temperature Devices/Materials for HEDS
• High Efficiency Low Cost Microwave Devices for U.S. Industries	• Very Long Life Materials/Component Systems for Space Applications
• High Efficiency PV Arrays for Domestic Use	• Support a Very Low Cost Space Launch
• Automated Systems for Manufacturing	• High Efficiency PV Arrays for Commercial Use
• Intelligent Smart Systems for Commercial Applications	• Large-Scale Low Cost Manufacturing for Components/Systems

if capital can be raised for 100 kW space solar satellites in space as a supplementary source of energy. Some of these technologies have already been used on space missions and others are planned for launch in the next 5 years.

b) Goals Set for the Technology. To be able to focus the investment on the greatest challenge to bring Space Solar Power closer to reality with the least amount of capital investment in research, it was critical to set a goal for each of the subsystems cost allowed to make the dream come true. The NASA Space Solar Power team developed a strategic technology for each of the meet the cost expectations to compete with the present terrestrial electricity market prices. Figure 6 shows the technology development approach. The NASA team is well aware that the standard is set too high and that environmental issues have to weigh in to enhance and enable the market economical benefit of clean energy. The proposed road map to achieve the set goal is shown in Figure 7.

Concluding Remarks

A continuous concern about evaluating any new energy resources and conversion systems, and especially those using renewable energy, is that the comparisons with competing systems be made on an equitable basis. At this time the price of electricity from conventional energy systems, such as those based on fossil or nuclear fuel, does not include many upstream and downstream costs, such as those of the environmental and health effects related to the benefaction of the fuels, and of those associated with various emissions and wastes. Furthermore, the depletion of the limited natural resources and of their exergy is not fully accounted for either. If these costs were included, space power would have a much easier competition with conventional power generation schemes.

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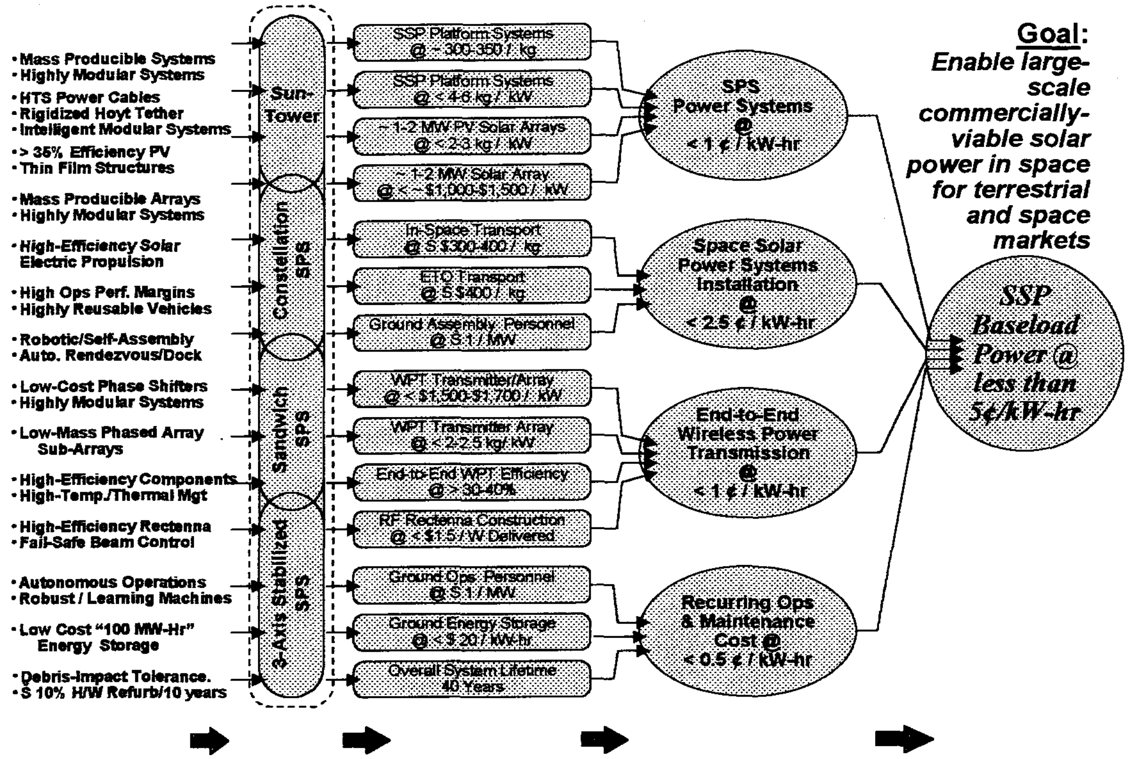

Figure 6. Space Solar Power Strategic Technology Approach

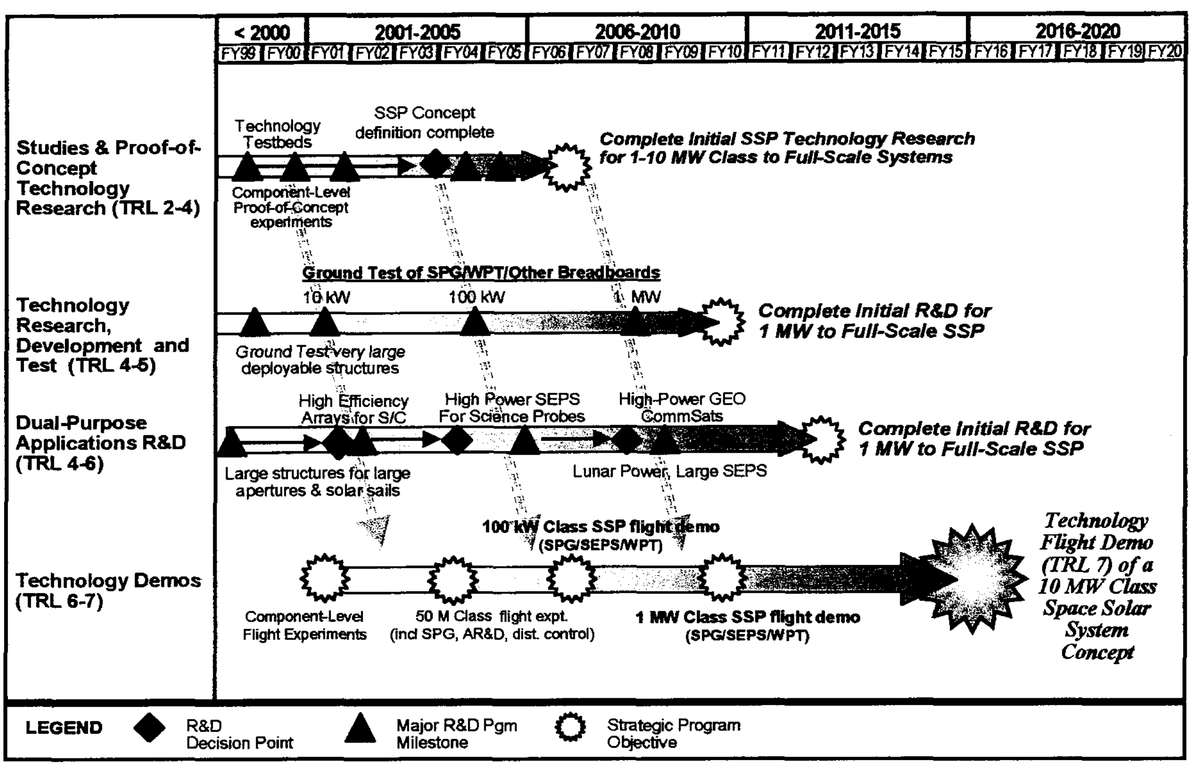

Figure 7. Space Solar Power Level A Technology Schedule/Milestone Roadmap